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Autonomous Crop Establishment and Control System

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Abstract

An advanced robotic crop establishment and control system was developed with the aim to target inputs at a higher spatial resolution to further increase the sustainability in crop production. The aim was to contribute to further optimise crop growth conditions. For the crop establishment a passive data logging system for seed mapping and an active grid seeder was developed. Furthermore, an inter-row hoe as well as an intra-row rotor weeder was developed to be mounted at the autonomous tractor. Vehicle navigation for tractors and implements between rows as well as the guidance of treatment tools can be based on seed map information. For seed mapping the range of the overall mean deviation between estimated seed position and true plant position was 16 – 43 mm. The inter-row hoe system enables hoeing up to 83 % of a field surface area with a speed of 2 km/h and up to 79 % by driving with 4 km/h. By assuming that conventional inter-row hoeing covers around 80 % of a total field surface additional or simultaneous intra-row weeding by a rotor weeder increases the result to up to 88 %. The robotic concept with the emphasis on even spatial crop establishment could be regarded as a system based on prevention rather than on curing principles.

1. Introduction

Today conventional or traditional farming varies inputs only from field to field using applicators set to constant dose rates for each individual field. New crop management strategies within Precision Farming divide fields up into sub-fields of similar soil or crop properties to address spatial variability by varying input dose rates per sub-field. Some research has been conducted with higher spatial resolutions than sub-field sizes but going down to individual plants [1], [2], [3]. These highly automated and information intensive systems aim at sensing single plant stresses and at targeting inputs in small dose rates adapted to individual crop plant needs (Plant Scale Husbandry).

An advanced robotic crop establishment and control system was developed with the aim to target inputs at higher spatial resolutions with the aim to further increase sustainability in crop production. Crop growth can be enhanced by altering spatial plant distributions [4], [5]. Crop plants arranged in even patterns better utilise resources like water, nutrients and space. Furthermore, the ability of the crop to suppress weeds is increased as well as even patterns

ease treatments for weed control. The later can be achieved for example by creating consistent even crop plant patterns across an entire field to allow cross hoeing [6].

The system comprising of different sensor and control units is able to log positional data during the seeding operation and use them for subsequent field operations [7], [8], [9], [3]. Vehicle navigation and guidance of tools for monitoring and treating individual crop plants are tasks which can be based on geo-referenced seeds derived from seeding operations.

The basic principle of the strategy is to optimise crop growth conditions. The proved assumption is that when using this system less inputs are required for direct treatments. The concept could thus be regarded as a preventing system rather than a curing system.

Increased crop spatial uniformity offers three major types of improvement for crop management: (i) higher yields and quality, (ii) increased weed suppression by the crop and (iii) new possibilities for improved effectiveness of treatments for physical weed control and application of chemicals. Main machinery system components are a precision seeder, an inter-row and intra-row weeder as well as a lawn mower and a sprayer (Figure 1). All implements are combined with an autonomous tractor. The system is fully unmanned and currently mainly GPS controlled.



Figure 1: Implements attached to the autonomous tractor for different field operations as sowing with seed mapping and grid seeding, weeding with inter-row and intra-row hoeing and grass mowing and spraying

2. Crop Establishment

For the crop establishment a passive data logging system for seed mapping and an active grid seeder was developed [2], [10]. The passive seeder allows a data recording during the

seeding operation to achieve a geo-referencing of seeds and hence rows. In a post processing procedure the recorded data are analysed and each seed can be geo-referenced. For subsequent field operations these absolute seed positions can be used e.g. for steering purposes (weeding parallel to crop rows) or for individual crop plant treatments within rows. The range of the overall mean deviation between estimated seed position and true plant position was 16 – 43 mm. Higher vehicle speeds always resulted in higher deviations compared with the values from the small seed spacing. Furthermore, as expected, the smaller seed spacing always gave higher deviations compared with the larger (202 mm) seed spacing. This can be explained by the zero-ground-speed effect when using the 202 mm spacing [2],

To arrange plants in very regular grids a special actively controlled seeder was developed which allows unit drive synchronisation within the working width, a synchronisation between passes and a very accurate control of the lateral row spacing between successive passes (side-shift). For achieving highly even plant grids a very accurate seed spacing is required. The seed placement is optimised in two dimensions in longitudinal and transversal directions. From the machine testing the values for mean spacing were very accurate and completely independent from the seeder unit and from the motor speed. In conclusion the motors were therefore able to drive the discs at a constant and very accurate speed. The standard deviations for the accumulated time per seed detection for the same spacing sequence between the four seeders were calculated. This parameter allows the evaluation of the synchronization between the rows. The mean of standard deviations was 4.23 ms. The test run was conducted with a 0.597 m/s forward speed. The mean absolute standard deviation was calculated to 2.53 mm. Assuming a normal distribution, 95 % of the data were in a range of ± 5.1 mm. Grid seeding with such a spacing accuracy has to be regarded as sufficient and very accurate. However, field experiments have to be conducted to investigate the effects under dynamic operation and field conditions [2].

3. Crop Control

Today farmers are interested in reducing herbicide use. Non-chemical inter-row and intra-row weeding are options but still very challenging field operations. An automatic inter-row hoe as well as an intra-row rotor weeder was developed to be mounted at the autonomous platform [7], [8]. Vehicle navigation between rows for implements and tractors as well as the guidance of treatment tools can be based on seed map information.

A conventional inter-row hoe was equipped with an electro-hydraulic side shift frame. The main task of the hoe controller system was to minimize the lateral deviations between current

GPS positions of the hoe related to a predefined route. The range of the cross track errors (standard deviations) altered between 0.009 m and 0.028 m for the hoe (ground measurements). The hoe system enables hoeing up to 83 % of a field surface area with a speed of 2 km/h and up to 79 % by driving with 4 km/h. The GPS based system showed its potential to be used for high accurate crop row guidance e.g. with an inter-row hoe [7].

A controller system for a weeding rotor (cycloid hoe) with individual tine switching was developed to allow weeding within crop rows. The trajectories of the tine rotor can be described as curves traced by a point on the circumference of a circle that rolls on a straight line (cycloid). Main parameters to achieve a particular tillage effect are the ratio of forward speed to rotational speed, the diameter of tine rotation, the lateral offset to crop rows, the number of tines and the shape or design of tine tips. The system consisted of a tine rotor including a parallelogram based attachment, ground wheel for depth control, hydraulic motor, speed deducting gearbox and a GPS based controller. The desired and active intra-row weeding operation by rotating and tilling tines requires accurate lateral and longitudinal control. A control of the rotor is needed to avoid crop plant damages. By knowing both the individual crop plant positions (seed map and/or optical sensor) and the current rotor position the absolute distance between tine circumference and crop plant can be calculated. Mechanical clutches within the rotor are activated as the crop distance falls below a definable value (trigger distance). By assuming that conventional inter-row hoeing covers up to 80 % of a total field surface (row width 0.500 m and width of untreated band 0.100 m) additional or simultaneous intra-row weeding by a rotor weeder increases the result to up to 88 % [8].

Experiments with a new concept for the precise application of herbicides have been conducted. The concept combines plant recognition, seed mapping, micro-dosing and autonomous robotics. The results show that the spray liquid can be applied at sub-centimeter accuracy and that the application rate can be reduced by two orders of magnitude compared to recommendations used for conventional broadcast spraying [9], [3].

4. Autonomous Platform

An autonomous tractor was used as the basis platform (Figure 2). This conventional 20 kW tractor (Hakotrac 3000) was retrofitted with an RTKGPS (Trimble MS750) and a controller system for navigation. The control of steering, engine speed, vehicle speed, PTO and three point linkage was achieved by using an electronic controller unit (ESX). Two electro-hydraulic valves (Sauer Danfoss EHP) actuate the steering and electric linear motors (Linak) control engine rpm and continuously variable transmission (CVT). The safety interlocks and emergency shutdown was achieved by a combination of stamp computers (with PIC

microcontrollers), radio links and hardwired relays. The tractor navigation controller was designed to follow a predetermined route plan accurately and repeatable across a field with planned action points for implement control [11], [12].

The controller system uses a multi-layer structure spanning from a hardware control server, over a low-level mobile robot controller, a high-level mission planner to a graphical user interface. A notebook computer as a user interface was linked by wireless local area network (WLAN) to the navigational tractor computer. The internet browser on the notebook displayed the graphical user interface of the navigation software and furthermore functioned to upload the mission files. A standard path tracker navigated the vehicle along way points. For turning at headlands, however, the tractor switched to predefined turning routines. Missions are defined using an XML formatted file that can be uploaded to the tractor through the user interface [12].

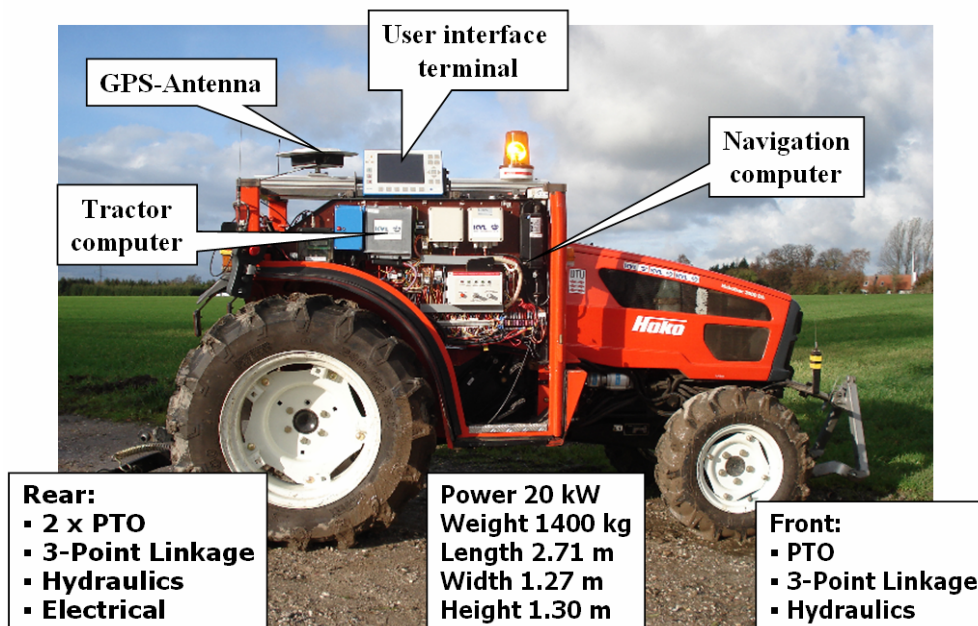


Figure 2: Autonomous tractor for different field operations as sowing, weeding, spraying and mowing.

The tractor was tested in combination with different implements. The main operations were as described seeding with seed mapping and inter-row and intra-row weed control. Other operations as mowing and spraying are prepared and will be tested soon. A centered mower was attached for operations in semi-public parks. In orchards a nozzle sprayers is available for weed control (herbicides) and a mist blower for pest control (insecticides). Currently a new research project is going on to investigate and increase safety, reliability and usability of the autonomous machine system.

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